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EVALUATION OF CANDIDATE MATERIALS FOR FIRE FIGHTER'S PROXIMITY SUITS

ROBERT M. STANTON

TECHNICAL REPORT AFML-TR-72-16

JULY 1972



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FOREWORD

This report was prepared by Robert M. Stanton of the Fibrous Materials Branch, Nonmetallic Materials Division, Air Force Materials Laboratory. The work was performed under Project No. 7320, "Fibrous Materials for Decelerators and Structures," Task No. 732002, "Fibrous Structural Materials," and was administered by the Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.

Fabrics evaluated in this report were selected for possible use in the specific area of military fire fighter's clothing. This evaluation should not reflect upon the use of these materials for industrial and consumer requirements for heat and/or fire resistance which are generally less severe.

This report covers work conducted from January 1971 to September 1971.

Any failure to meet the objectives of this study is no reflection on the commercial items discussed herein or on their manufacturers.

The author wishes to express his appreciation to the personnel of the Coatings Section of the Elastomers and Coatings Branch for assistance in attaining the reflectivity data and to the Thermally Protective Plastics and Composites Section of the Plastics and Composites Branch for the loan of the quartz lamp facility.

Also contributing to the attainment of the raw data were Mr. R. Cornwell, Mr. W. Miller, and Mr. B. Byrd.

This technical report has been reviewed and is approved.



J. H. ROSS
Chief, Fibrous Materials Branch
Nonmetallic Materials Division

ABSTRACT

Lightweight protective fabrics are needed for incorporation into fire fighter's proximity suits to provide protection, comfort, and increased mobility to the wearer while fighting liquid fuel (JP-4) fires. Candidate materials which are commercially available are evaluated on the basis of protection from radiant heating exposures and for flammability and mechanical properties. Novatex and Fypro shell fabrics in combination with a neoprene water barrier and a Nomex needle punch felt will provide a high degree of protection and increased comfort and mobility for wearers while fighting liquid fuel fires.

TABLE OF CONTENTS

SECTION		PAGE
I	INTRODUCTION	1
II	THERMAL ENVIRONMENT	2
III	MATERIALS EVALUATED	3
IV	TEST PROCEDURES	6
V	DISCUSSION	9
VI	CONCLUSIONS	24
	REFERENCES	25

LIST OF TABLES

TABLE		PAGE
I	Shell Fabrics Evaluated	4
II	Battings Evaluated	5
III	Reflective Fabric Characteristics	10
IV	Reflectance Data for Abraded Fabrics	11
V	Lay-up and Exposure Levels for Reflective Fabrics	13
VI	Evaluation of Battings	16

LIST OF ILLUSTRATIONS

FIGURE		PAGE
1.	Schematic and Photograph of Test Apparatus - Quartz Lamp Facility	7-8
2.	Shell Fabrics (As Received)	17
3.	Shell Fabrics (As Received)	18
4.	Shell Fabrics	19
5.	Reflective Fabrics Over Batting No. 202	20
6.	Reflective Fabrics Over Batting No. 202	21
7.	Reflective Fabrics Over Batting No. 202	22
8.	Battings - Covered w/Abraded No. 204	23

SECTION I

INTRODUCTION

Department of Defense personnel involved in fighting aircraft accident fires and rescuing crewmen trapped inside the burning fuselages must currently use bulky, heavy, and stiff aluminized ensembles which tend to inhibit movement and after a short life span the garments start to lose their protective capability due to wear of the aluminized surface. Recent advances in the state-of-the-art in fire resistant and nonflammable fibrous materials have led to the development of lighter weight and thermally protective fabrics which should be incorporated into fire fighter's clothing. The Air Force Materials Laboratory was requested to undertake this program by the Aircraft Ground Fire Suppression and Rescue Systems Program Office (AGFSRS) in accordance with Air Force Systems Command Required Operational Capability (ROC) No. 1-70, dated 15 June 1970. As outlined in ROC, present Defense Supply Agency procured fire fighter's protective clothing ensembles weigh approximately 27-32 lbs per suit and have an average life span of about six months. The ROC also states that some of the components are flammable. Fire fighters need protective clothing with reduced weight and bulk to provide increased mobility and to prevent wearer fatigue. The objectives of this program were to evaluate current state-of-the-art materials, supplied by AGFSRS, to establish their ability to provide equal or superior protection for fire fighters from JP-4 fuel fires and to insure improved fabric durability and nonflammability with lightweight, more flexible materials to enable reduction of the present weight from 27-32 lbs per suit down to at least 10 lbs per suit.

SECTION II

THERMAL ENVIRONMENT

The referenced ROC outlines the protection requirements of noncombustibility and heat reflectance so that the wearer would be protected against radiant heat from an 1800°F flame source for at least two minutes without reaching the pain threshold temperature of 113°F (Reference 1). Utilizing modern day fire suppression equipment the above requirements would seem reasonable. However, under severe conditions, fire control times, with fire fighting equipment on the scene, can take as long as 160 seconds and can subject the fire fighters to blackbody temperatures as high as 2200°F (Reference 3). Graves (Reference 3) concluded that the maximum radiative heat transfer to a vertical surface in the near vicinity of a JP-4 fuel fire would be 1.9 cal/cm²-sec. Recent studies by Veghti (Reference 4) have demonstrated combined convective and radiative heating to a surface four feet from the edge of a burning JP-4 fuel fire to be as high as 2.7 cal/cm²-sec. Although these higher heating rates can occur the average incident radiant energy that fire fighters are subjected to is from 0.70 cal/cm²-sec to 0.86 cal/cm²-sec with the majority of the energy being emitted within the 0.6 μ to 6.0 μ wavelength range (References 2, 3, 5).

Discussions with the Aircraft Ground Fire Suppression and Rescue SPO have led to the belief that the fire fighters are normally exposed to the lower levels of heating (i. e., 0.7 cal/cm²-sec). Rarely, if ever, do they come in direct flame contact with, or advance on a fire from the down wind side where convective heating would be severe. From the above it was decided to evaluate the various materials at heating rates from 0.7 to 2.5 cal/cm²-sec with emphasis on the 0.7 to 1.3 cal/cm²-sec heating range. It should be noted that these materials have been rated on the basis of radiant energy exposures for fire proximity suits. Although the vertical strip test was used to determine whether or not these materials would continue to propagate flames this does not imply that these materials could withstand direct flame impingement from a JP-4 fuel fire for fire entry purposes.

SECTION III

MATERIALS EVALUATED

The present fire fighter's ensemble consist of an outer shell reflective (aluminized) fabric to ward off radiant energy, with an underlying water barrier to prevent moisture penetration or build-up and a quilted wool batting with a rayon lining (MIL-C-82260). The reflective outer shell fabrics are outlined in Table I. All of the shell fabrics are coated with aluminum with the exception of Specimen No. 201 which is made of a vinyl binder, fiberglass, and an aluminum pigment combination. The shell fabrics were evaluated with and without underlying battings. Batting No. 202 was used for the shell fabric evaluations because of its availability and ease of handling due to a built in water barrier. The 3M processes was used to aluminize the fabrics. The aluminum is vapor deposited on a film and then transferred to the base fabric, followed by removal of the film. Since fire fighters are constantly exposed to moisture both from inside and outside the suit, the battings evaluated (Table II) required a separate water barrier to prevent moisture buildup, except for batting No. 202 which has a built in water barrier. The prevention of moisture buildup is required because moisture, regardless of source, increases suit weight and presents a secondary hazard to the wearer of increased heat transmission and the possibility of super heating the moisture which could in turn cause severe burns. Batting No. 202 consists of a film coated cheese cloth, which serves as a water barrier, over the wool batting and rayon lining. The remaining battings require a separate water barrier. For these evaluations a 5.8 oz/yd², neoprene coated nylon water barrier was used in combination with all of the battings except batting No. 202.

TABLE I
SHELL FABRICS EVALUATED

Log No.	Description	Weight	Thickness (mils)
201	Vinyl coated fiberglass (VFG) Aluminum pigmented	20.9	33
203	Aluminized Novatex	11.2	23
204	Aluminized Nomex	5.1	12
205	Aluminized Asbestos/Cotton MIL-C-82249A (present standard shell fabric)	23.4	41
206	Aluminized Kynol	7.2	19
219	Aluminized Fypro	10.7	28

TABLE II
BATTINGS EVALUATED

Log No.	Description	Weight Oz/yd ²
202	Coated cheese cloth/Reprocessed wool/Rayon lining	19.4
208	Kynol batt w/Kynol lining on both sides	16.9
216	Reprocessed wool. w/rayon lining on both sides MIL-C-82260 (present standard batting)	15.2
218	Nomex batt w/Nomex lining on both sides	16.9
220	Nomex needle punch felt	6.7

SECTION IV

TEST PROCEDURES

Materials were exposed to infrared heating from a Research Incorporated, High Density Heater, Model 5208 with T3/CL/HT, tungsten iodine lamps (Figure 1). A clear quartz window is used to protect the lamps from smoke and/or tar deposits. The heating rate was monitored and controlled by a Medtherm Total Heat-Flux Transducer, water cooled, No. 64-10-20-T in combination with a Research Incorporated Thermac Controller No. TC5192 RR MV10. Heating rates did not vary more than 2%. The samples were mounted as shown in Figure 1. Samples evaluated without battings were placed in direct contact with the skin simulatant and when a batting was used a 0.25-inch spacer was used to maintain a constant thickness from sample to sample. The desired level of heating with uniform heat flux density was reached in less than one second over a 1-inch diameter circular exposure area. The sample surface and the heat flux transducer were placed 1.5 inches from the lamp surface. A complete description of the quartz lamp facility may be found in Reference 6.

Reflectance data in the 0.25 to 25 μ range was measured with a Gier-Dunkle portable IR reflectometer (No. DB 100). Flame resistance and fabric mechanical characteristics were measured in accordance with Fed. Test Method Std. No. 191, with the abrasion data excepted.

Attainment of uniform abrasion data by any technique is difficult. The fragile nature of the aluminized fabrics made this task even more difficult. Abrasion instruments available for this program were the Schiefer abrader, Method No. 5308 and the Tabor abrader Method No. 5306. The abrasants normally used with these instruments were found to be too severe and resulted in highly scattered data. Going on the assumption that the nonuniform abrasion was not a characteristic of the materials, a more suitable abrasant was sought. An 8.6 oz/yd² cotton sateen cloth abrasant (MIL-C-557F) was used on the Schiefer abrader with a 1.5 pound head load. This technique was chosen because it provided consistent wear for a given fabric type.

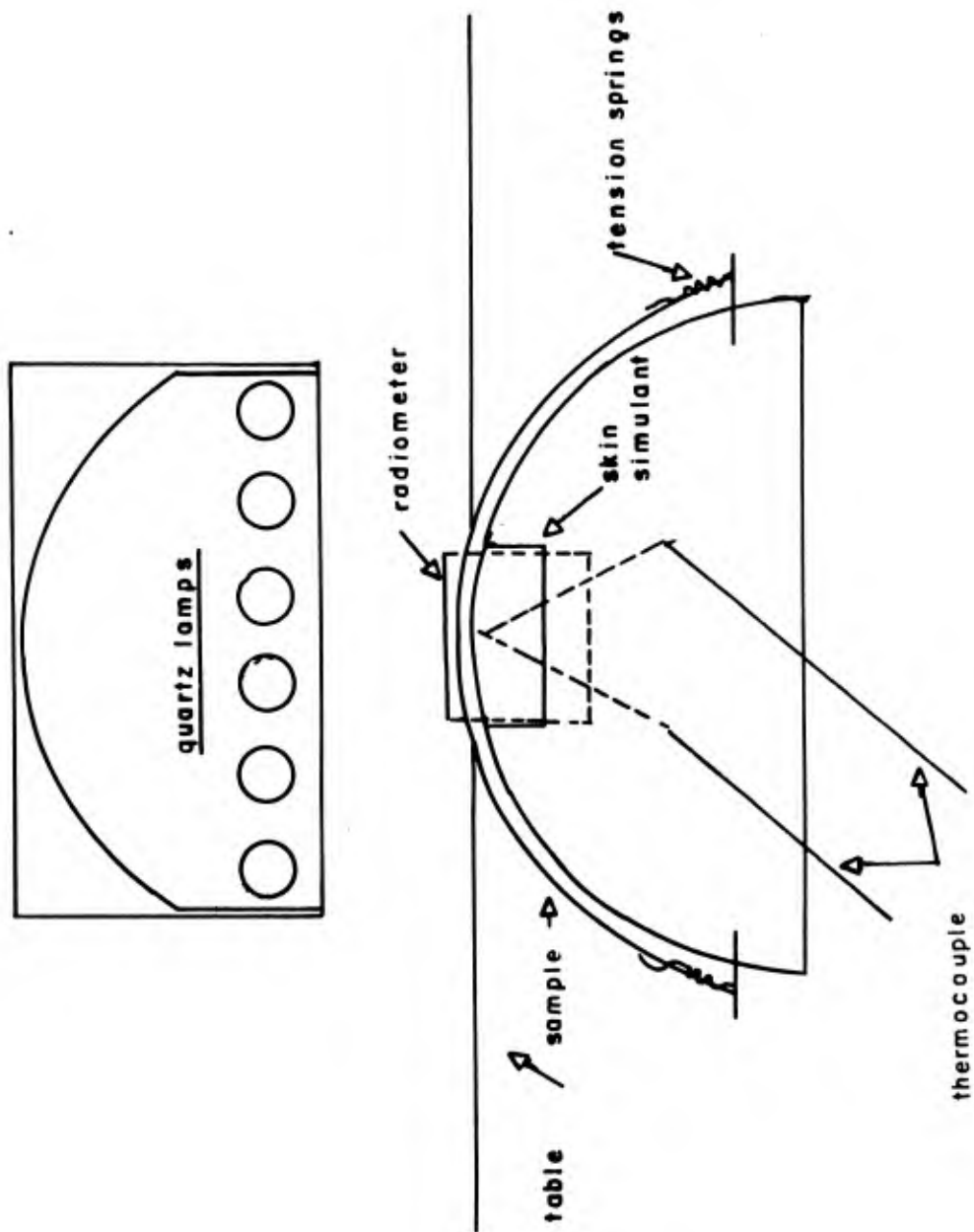


Figure 1a. Schematic and Photographs of Test Apparatus - Quartz Lamp Facility

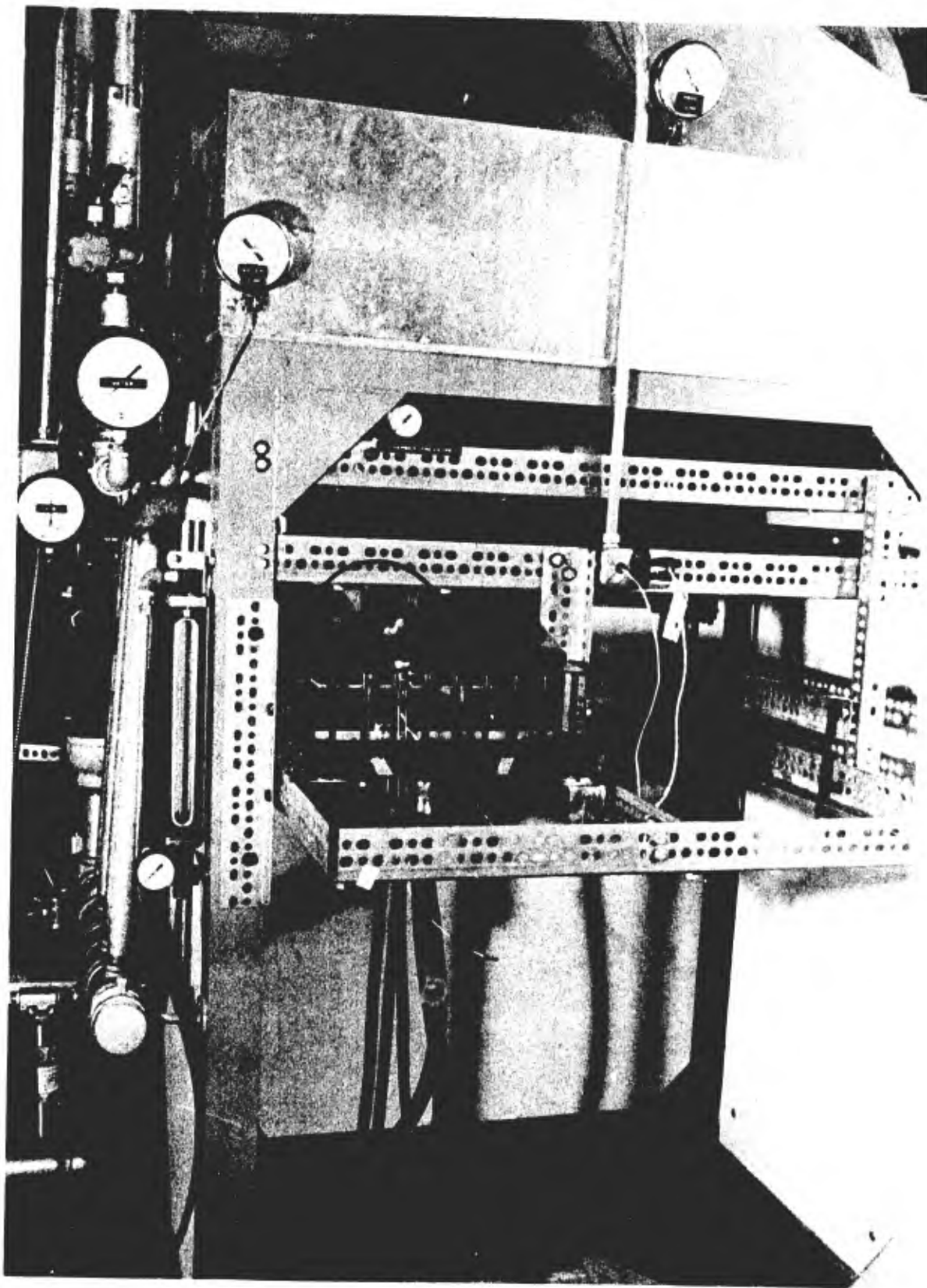


Figure 1b. Schematic and Photographs of Test Apparatus - Quartz Lamp Facility

SECTION V

DISCUSSION

All of the outer shell fabrics have tearing and breaking strengths in the range of the currently used fabric, with the exception of the aluminized Kynol, No. 206 (Table III). Current AFML sponsored development is geared towards the improvement of the mechanical characteristics of Kynol fiber which might make it a more acceptable base fabric for this application. The VFG fabric slipped in the Instron jaws during tensile testing and suitable tearing data was not obtained because of diagonal tearing. Further mechanical data was not determined for the VFG fabric because it was deemed unacceptable due to its poor reflectance data.

Reflectance data (Table III) and visual observations of the abraded samples give evidence of uniform wear from sample to sample for each fiber type. Of the aluminized fabrics, No's. 203, 205, and 219 exhibited the best retention of their reflective surfaces.

Fold endurance data (Table III) showed that the stiffer and thicker the sample the worse the hole and crack formation became. This is probably due to greater stress created during bending on the outer aluminized surface as fabric thickness and stiffness is increased. Garments to be made from these shell fabrics are constantly subjected to hard and abrasive wear during usage. The trousers are pushed and folded downward over the boots and both the jackets and the trousers are constantly stored and removed from lockers, and thrown on to fire trucks causing the shell fabrics to be continuously flexed and abraded. Since the protection provided the wearer is highly dependent upon the reflectance of the shell fabric, resistance to flexing and abrasion is very important. The abrasion data yields somewhat different results than the fold endurance data. The thicker and stiffer fabrics were more resistant to abrasion. Thus, a development effort should be undertaken to determine the advantages and/or the disadvantages of varying fabric thickness and stiffness to establish optimum construction parameters. Considerations would also have to be given to wearer comfort because the wearers desire a more flexible garment than presently used.

TABLE III
REFLECTIVE FABRIC CHARACTERISTICS

Log No.	Break Strength ⁽¹⁾		Tear Strength ⁽²⁾		Fold Endurance ⁽³⁾		Stiffness ⁽⁴⁾			Flame Resistance ⁽⁵⁾		
	Warp (lbs/in)	Fill (lbs/in)	Warp (lbs)	Fill (lbs)	Warp & Fill Visuals	Warp Over hang (ins)	Flex (G) (in/lb) ⁴ (x10 ⁻⁴)	Over hang (ins)	Flex (G) (in/lb) (x10 ⁴)	Glow Time (sec)	Flame Time (sec)	Char Length (inches)
(Vinyl) 201	N. D. [*]	N. D. [*]	N. D. [*]	N. D. [*]	No change	3.2	41	3.0	34	3.6	0	.33
(Novatex) 203	125	85	12.6	N. D.	Crack & Hole Formation (C&H)	>6	-	5.8	128	1.0	0	0
(Nomex) 204	156	134	5.5	6.4	No change	3.7	16	4.3	24	1.6	0	5.6
(Mil-Sped) 205	140	59	10.4	13.7	C & H	5.3	210	5.3	210	4.0	0	0
(Kynol) 206	59	26	2.2	3.0	C & H	3.2	14	2.7	9	29.0	0	1.9
(Fypro) 219	310	166	13.7	12.8	Sever	>6	-	>6	-	5.0	0	1.5

* Fabric tore diagonally

1) Method No. 5100

2) Method No. 5136

3) M. I. T. Fold Endurance Tester (500 cycles)

4) Method No. 5206.1, $G = C^3 \times W \times 0.482 \times 10^{-4}$

5) Method 5903.1

TABLE IV
 REFLECTANCE DATA FOR ABRADED FABRICS (%)
 (CCC-T-1916 No. 5308-1, SCHIEFER ABRADER, 500 CYCLES)
 (1.5 lb. Head Load, Cotton Cloth abradant)

Sample No.	1	2	3	4	5	1A	2A	3A	4A	5A	6A	1B	2B	3B	4B	5B	6B	7B	Average	As Received
Log No. 201	30	30	29	29	30	-	-	-	-	-	-	-	-	-	-	-	-	-	30	33
203	87	86	85	82	83	90	90	89	92	87	89	-	-	-	-	-	-	-	87	95
204	73	84	83	77	77	81	82	81	83	83	83	84	83	79	88	83	83	81	86	94
205	87	92	91	92	88	87	91	86	90	89	87	-	-	-	-	-	-	-	89	91
206	87	81	78	88	83	80	84	83	80	86	83	-	-	-	-	-	-	-	83	94
219	93	94	85	93	90	86	86	88	86	89	89	-	-	-	-	-	-	-	89	94

From a nominal room temperature of approximately 25°C a temperature rise of 21°C would attain the pain threshold temperature for human skin. This corresponds to approximately 0.9 millivolts e. m. f. generated in the copper constantan thermocouple imbedded in the skin simulant heat sensor used in these experiments. The response curves for the fabrics exposed to radiant heating are shown in Figures 2 through 8. Approximate times to reach the pain threshold temperature can be determined by the time corresponding to 0.9 millivolts for the respective curves.

Table V outlines the sample configuration and exposure conditions for the radiant heating exposures. The code numbers as written defines first the sample number followed by the curve number and finally the abraded sample number. Where an asterisk appears in place of the final number the shell fabric was tested as received without being abraded.

The aluminized fabrics as received all withstood heating rates from 0.7 to 2.5 cal/cm²-sec for five minutes without showing signs of deteriorating (Figures 2 and 3). For the curves shown in Figures 2, 3, and 4, the backside of the aluminized fabric was held in intimate contact with the skin simulant. The simulant responds as a heat sink preventing the fabric from attaining the higher temperatures that would be realized by the fabric if an air gap was present between the fabric and simulant. This does however provide useful information for later comparisons as to how much additional protection is provided by the battings, and it also provides a direct comparison for the abraded vs. unabraded fabrics response curves in Figure 4.

Examination of Figures 3 and 4 shows that large temperature gradients do not result from one fabric type to another during five minute heating time. But even a small temperature difference can represent a large difference in protection time dependent upon at which point the respective curves intercept the 0.9 millivolt line. (e. g. , the protection time for curve No. 16, Figure 3 at 1.9 cal/cm²-sec is approximately 155 seconds while for curves 12, 13, and 15 the protection time is approximately 70 seconds). Protection times derived in this manner are based on the use of simulated skin theory. Therefore protection times stated can only be considered approximate. More exact burn data could only be determined using live animal skin and extensive pathological analysis.

TABLE V
LAY-UP AND EXPOSURE LEVELS FOR REFLECTIVE FABRICS

Exposure Level Cal/cm ² -sec	NO BATTING						BATTING IN PLACE **		
	Sample No. / Curve No. / Abraded No.								
Log No.	0.7	1.3	1.9	2.5	.7	.7	1.3	1.9	
201	7-3-* 8-3-* 9-3-*	---	---	---	61-22-1	---	---	---	
203	1-1-* 2-1-* 3-1-*	16-7-* 17-7-*	26-12-* 27-12-*	36-17-*	46-23-1 47-23-4 48-23-3	62-28-* 63-28-5 64-28-2	75-33-* 76-33-6A 77-33-5A	90-38-* 91-38-4A 92-38-3A	
204	4-2-* 5-2-* 6-2-*	18-8-* 19-8-*	28-13-* 29-13-*	38-18-*	49-24-1 50-24-2 51-24-4	65-29-* 66-29-3 67-29-5	78-34-* 79-34-6A 80-34-5A	93-39-* 94-39-4A 95-39-3A	
205	10-4-* 11-4-*	20-9-* 21-9-*	30-14-* 31-14-*	40-19-*	52-25-5 53-25-1 54-25-2	68-30-* 69-30-3	81-35-* 82-35-6A 83-35-5A	96-40-* 97-40-4A 98-40-3A	
206	12-5-* 13-5-*	22-10-* 23-10-*	32-15-*	42-20-*	55-26-1 56-26-2 57-26-3	70-31-* 71-31-4 72-31-5	84-36-* 85-36-6A 86-36-5A	99-41-* 100-41-4A 101-41-3A	
219	14-6-* 15-6-*	24-11-* 25-11-*	34-16-*	44-21-*	58-27-1 59-27-2 60-27-3	73-32-* 74-32-4	87-37-* 88-37-6A 89-37-5A	102-42-* 103-42-4A 104-42-3A	

* Sample as Received - Not Abraded

** Batting No. 202 for all samples.

When the shell fabrics are subjected to the abrasion techniques described earlier in this report, the differences in heat transmission from one fabric type to another become quite noticeable (Figure 4). The fabrics with more "body" or greater thickness and stiffness are more resistant to the abrasion techniques used (Figure 4, Curves 23, 25, and 27). The aluminum pigmented, vinyl-fiber glass (No. 201) yielded poor results when subjected to radiant heating both before and after abrasion (Figure 4, Curves 3 and 22). These results were anticipated because of the low reflectance data for the vinyl fabric. Review of Figures 2, 3, and 4 demonstrate the importance of maintaining the reflective coating to ward off incident radiant heat. Protection times were severely reduced by abrading the aluminized surface with protection times at the $0.7 \text{ cal/cm}^2\text{-sec}$ heating rate ranging from 10 seconds to 230 seconds (Figure 4) for the abraded fabrics while the response curves for the unabraded samples remained below the 0.9 millivolt level throughout the five minute exposure time.

Figures 5, 6, and 7 are the response curves for the shell fabric-water barrier-batting combinations. Throughout the range of heating rates all of the as received combination samples provided protective capabilities below the 0.9 millivolt response level. The abraded combinations degraded rapidly as a thermal barrier with increasing heating rates. Smoke evolved from both of the aluminized Kynol and Nomex samples after 30 seconds at the $0.7 \text{ cal/cm}^2\text{-sec}$ exposure level while the Novatex, Fypro, and standard remained undamaged.

At $1.3 \text{ cal/cm}^2\text{-sec}$, abraded Novatex, Nomex, and Kynol all evolved smoke between 12 to 15 seconds and the Fypro and standard fabrics showed no signs of smoking. During the lower exposure level ($0.7 \text{ cal/cm}^2\text{-sec}$) the water barrier for the Kynol and Nomex layups was fused to the back of the shell fabric at all higher energy levels; all of the abraded lay-ups exposed, regardless of fiber type, had the water barrier fused to the back of the abraded shell fabric.

Smoking occurred in less than seven seconds for abraded Novatex, Nomex, and Kynol at the $1.9 \text{ cal/cm}^2\text{-sec}$ exposure level. Abraded Fypro and the standard shell fabrics evolved smoke after 30 seconds.

Heat transmission for the abraded lay-up exposed at $1.3 \text{ cal/cm}^2\text{-sec}$ was rapid (Figure 6) for Kynol and Nomex. Fypro, Novatex, and standard lay-ups continued to provide protection, but only Fypro maintained the thermocouple response below 0.9 millivolts.

Upon increasing the exposure level to $1.9 \text{ cal/cm}^2\text{-sec}$ the aluminized Fypro fabric showed a sharp rise in temperature. Examination of the sample revealed damage to the base fabric causing degradation of the aluminized surface thus allowing a rapid rise in temperature. The Novatex and standard material still provide good protection while the Nomex and Kynol samples provided little protection (Figure 7) at $1.9 \text{ cal/cm}^2\text{-sec}$.

Table VI lists the batting combinations tested (shell fabric No. 204 used for all lay-ups). The battings are comparable more so on the basis of configuration rather than fiber type. Battings 202 and 218 allowed the fastest heat passage and the Kynol (208), and the standard batt (216) and the Nomex needle punch felt (220) insulation layers yielded similar curves to each other (Figure 8). The Nomex needle punch felt (No. 220) has the best combination of thermal protection and light weight.

These laboratory evaluations yield strong indications that some of the candidate materials excel in resistance to wear and thermal protection especially at severe heating rates. Fire fighters as well as personnel from AGFSRS have expressed some doubt that the higher exposure levels chosen for these tests would not actually be seen for five minute exposures by firemen. The tests were designed to show the relative merits of the candidate fabrics. From these results one cannot state exact protection times, but the data does express relative protective differences from fabric to fabric. How much protection is actually offered can only be determined through usage of the candidate fabrics in the field. The importance of these tests is to eliminate the weaker candidates so that costly operational test and evaluations will not have to be conducted for all candidate fabrics and also to prevent unnecessary injury to the individual wear testing the candidate ensemble.

TABLE VI
EVALUATION OF BATTINGS
(REFLECTIVE FABRIC NO. 204 USED FOR ALL SAMPLES)

Exposure Level	1.3 Cal/cm ² -sec Sample No./Curve No./Abraded No.
Log No.	
202	79-34-6A 80-34-5A
208	109-43-7B 110-43-6B
216	113-44-2B 114-44-1B
218	105-45-2A 106-45-1A
220	111-46-5B 112-46-3B

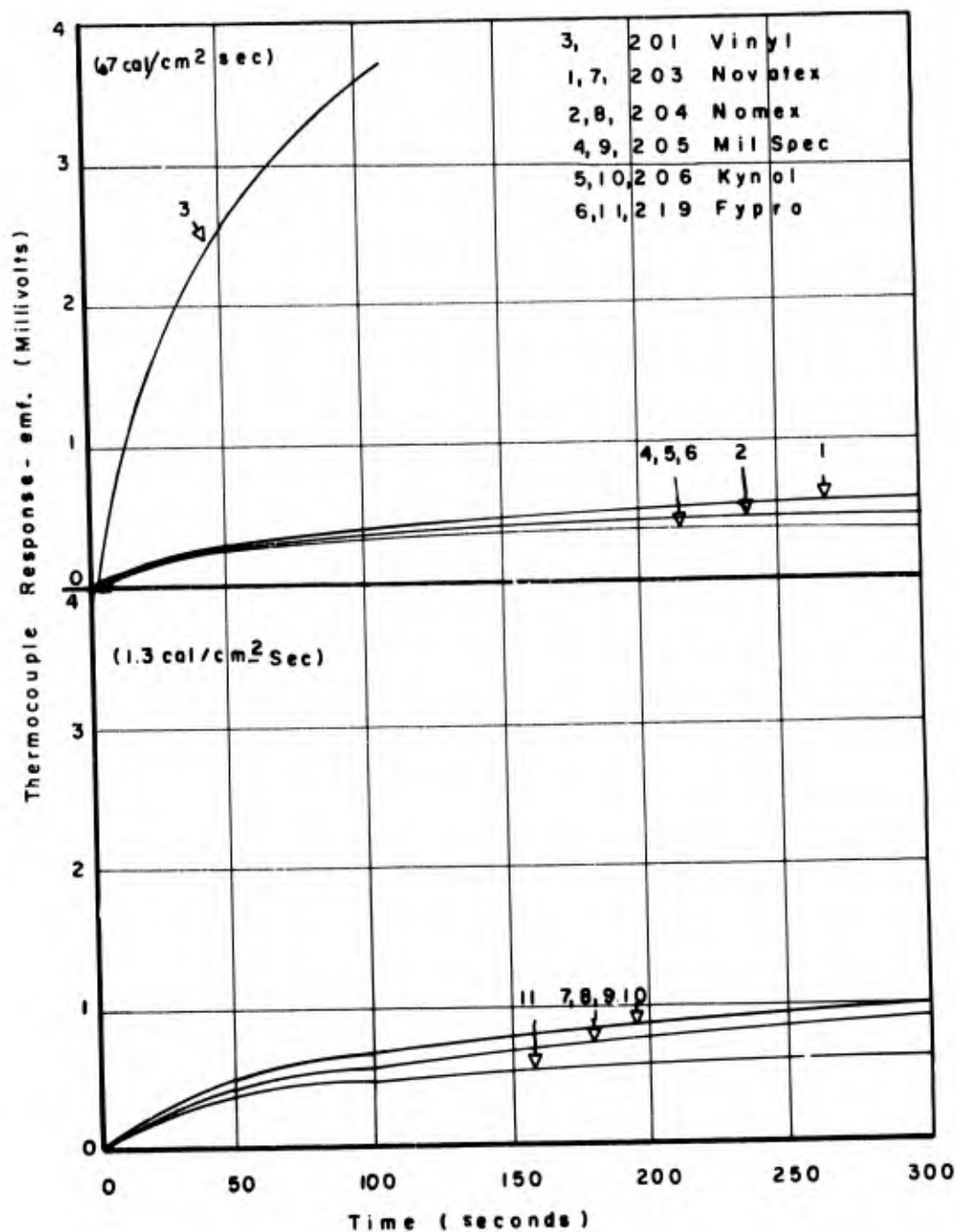


Figure 2. Shell Fabrics (As Received)

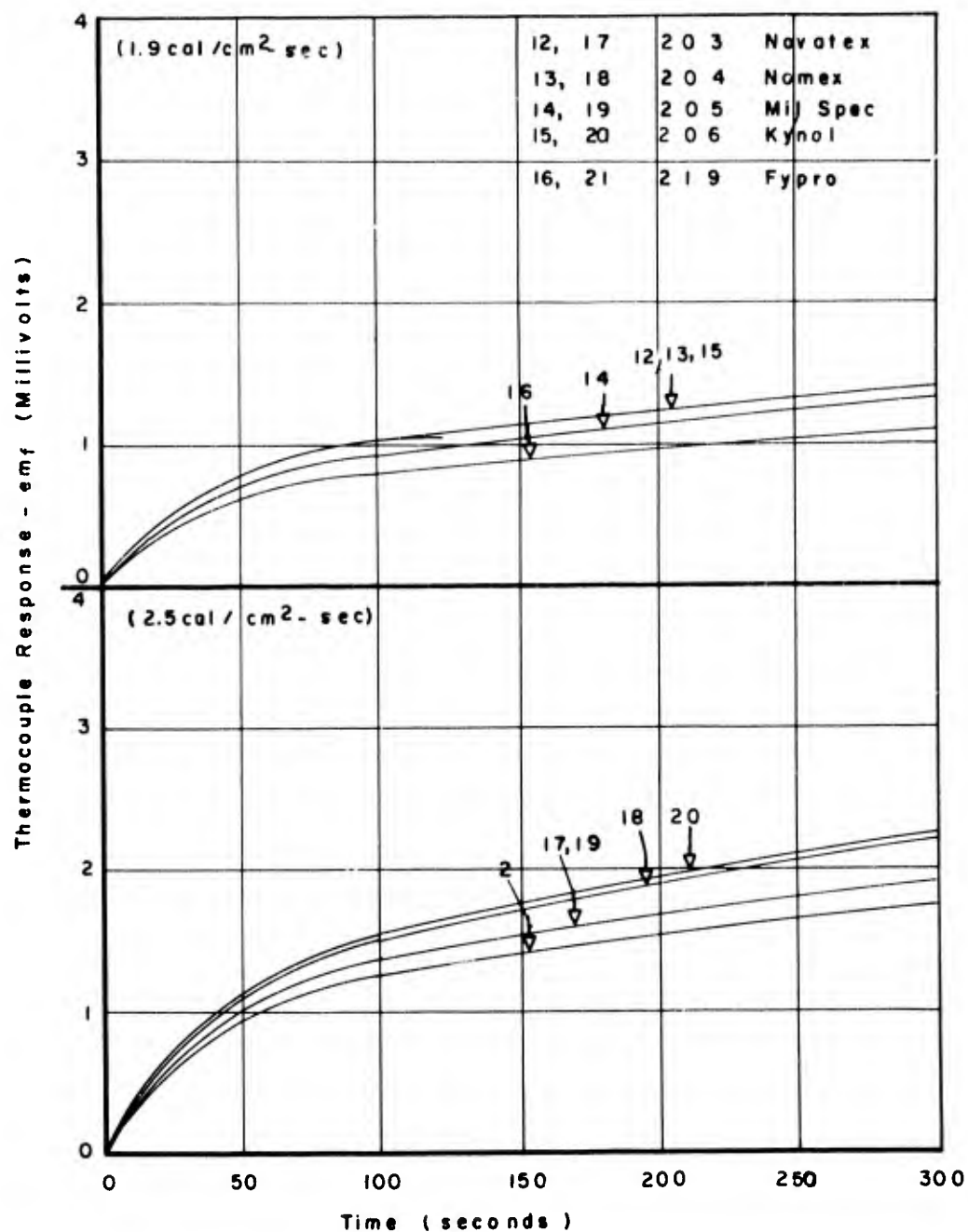


Figure 3. Shell Fabrics (As Received)

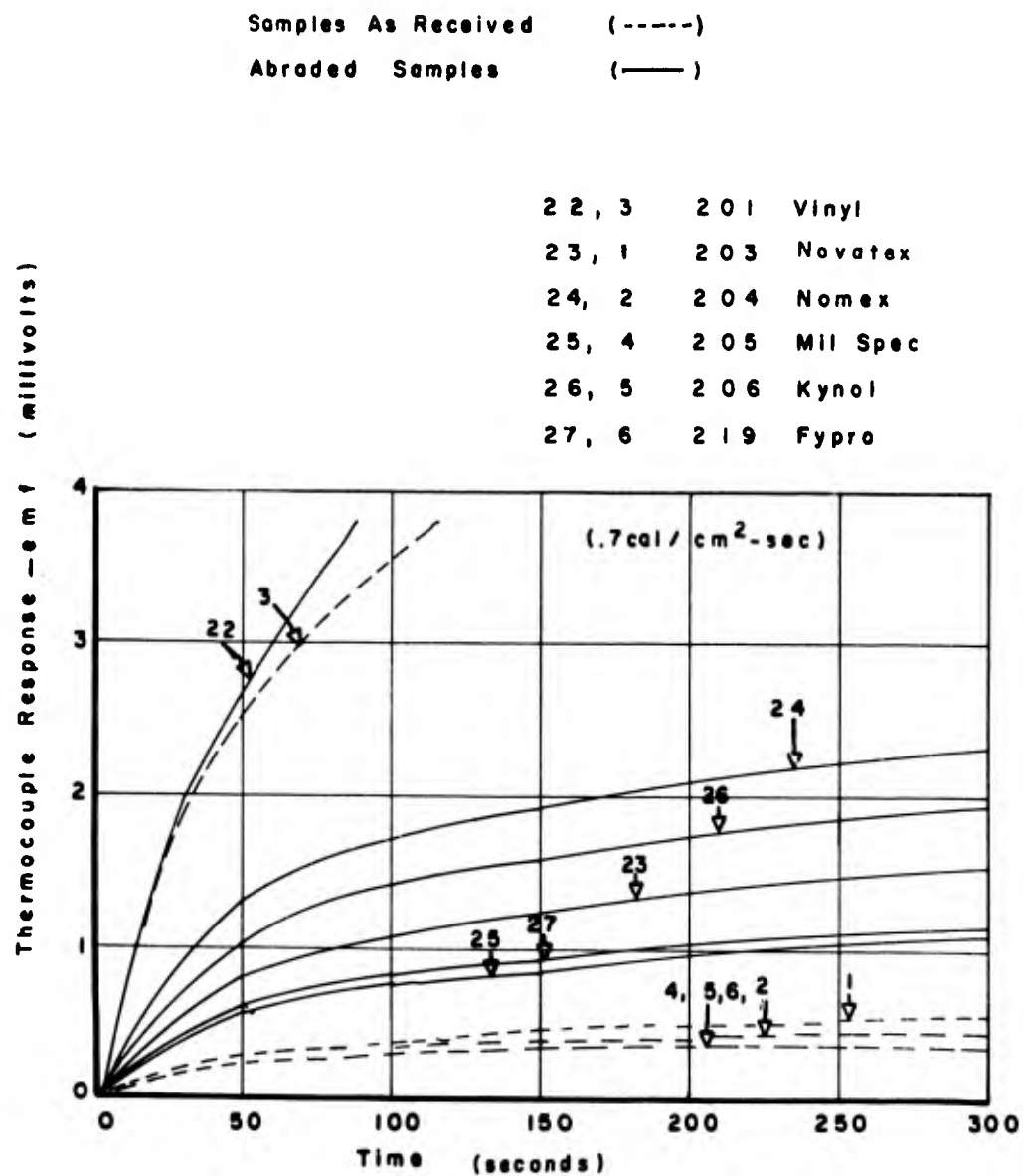


Figure 4. Shell Fabrics

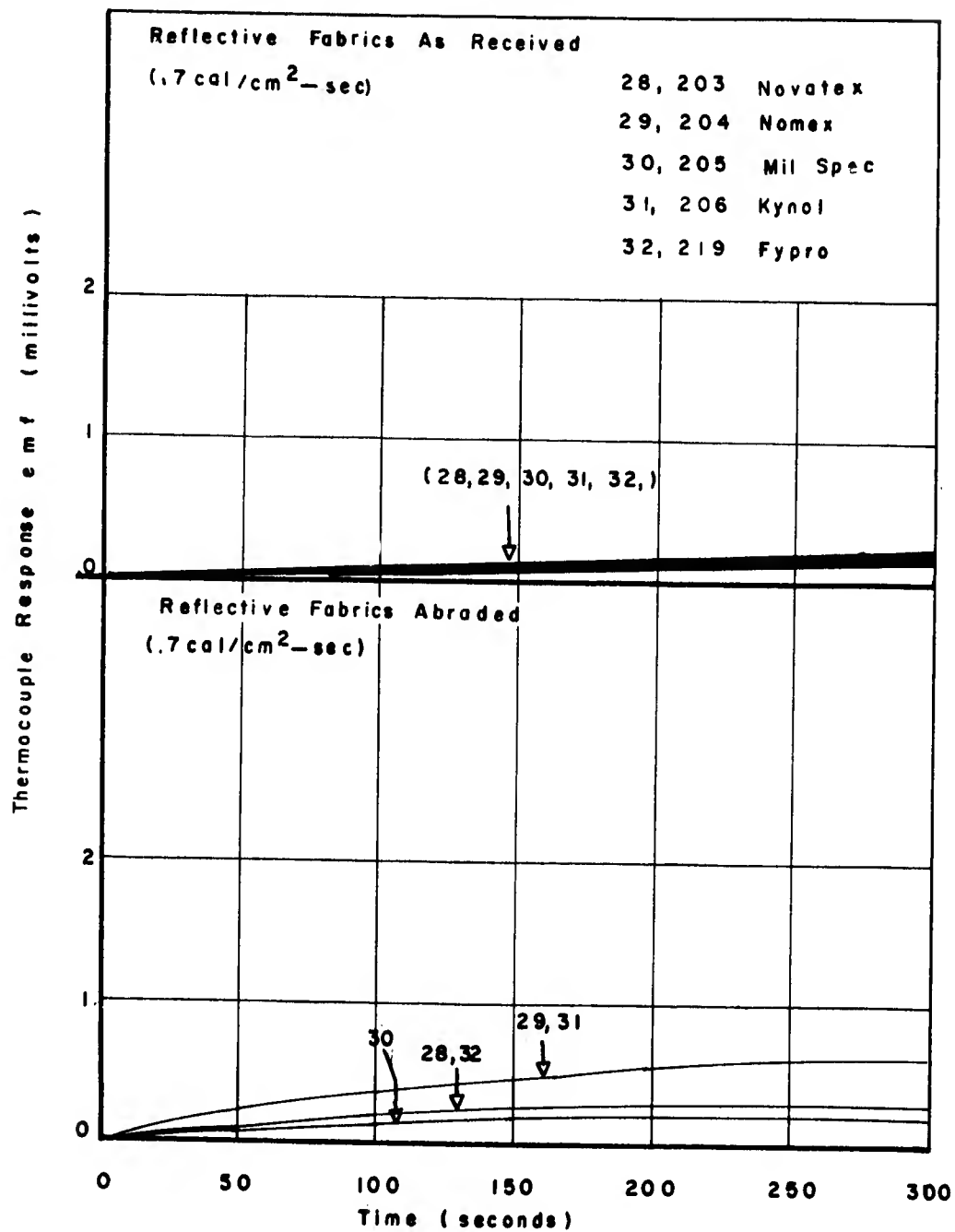


Figure 5. Reflective Fabrics Over Batting No. 202

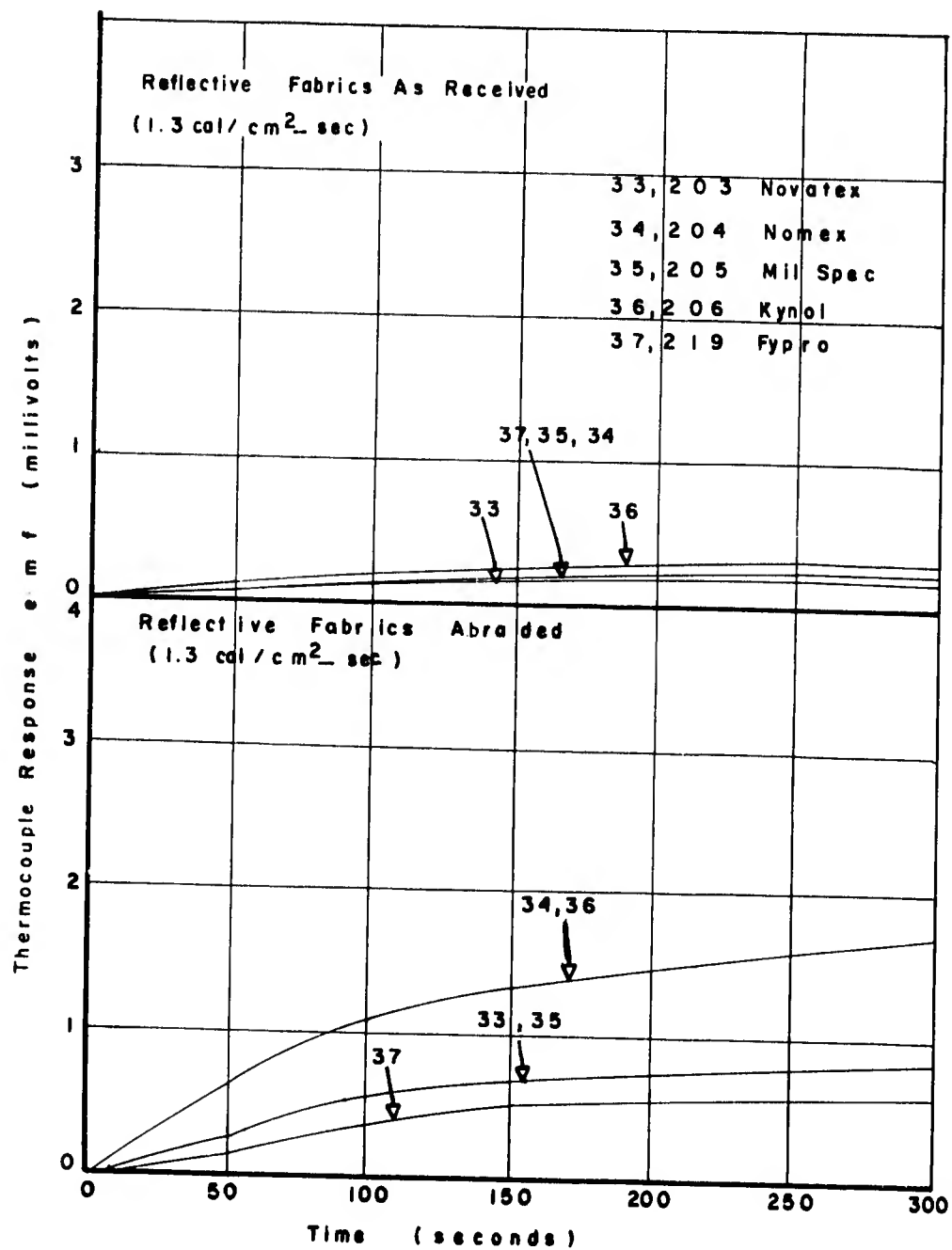


Figure 6. Reflective Fabrics Over Batting No. 202

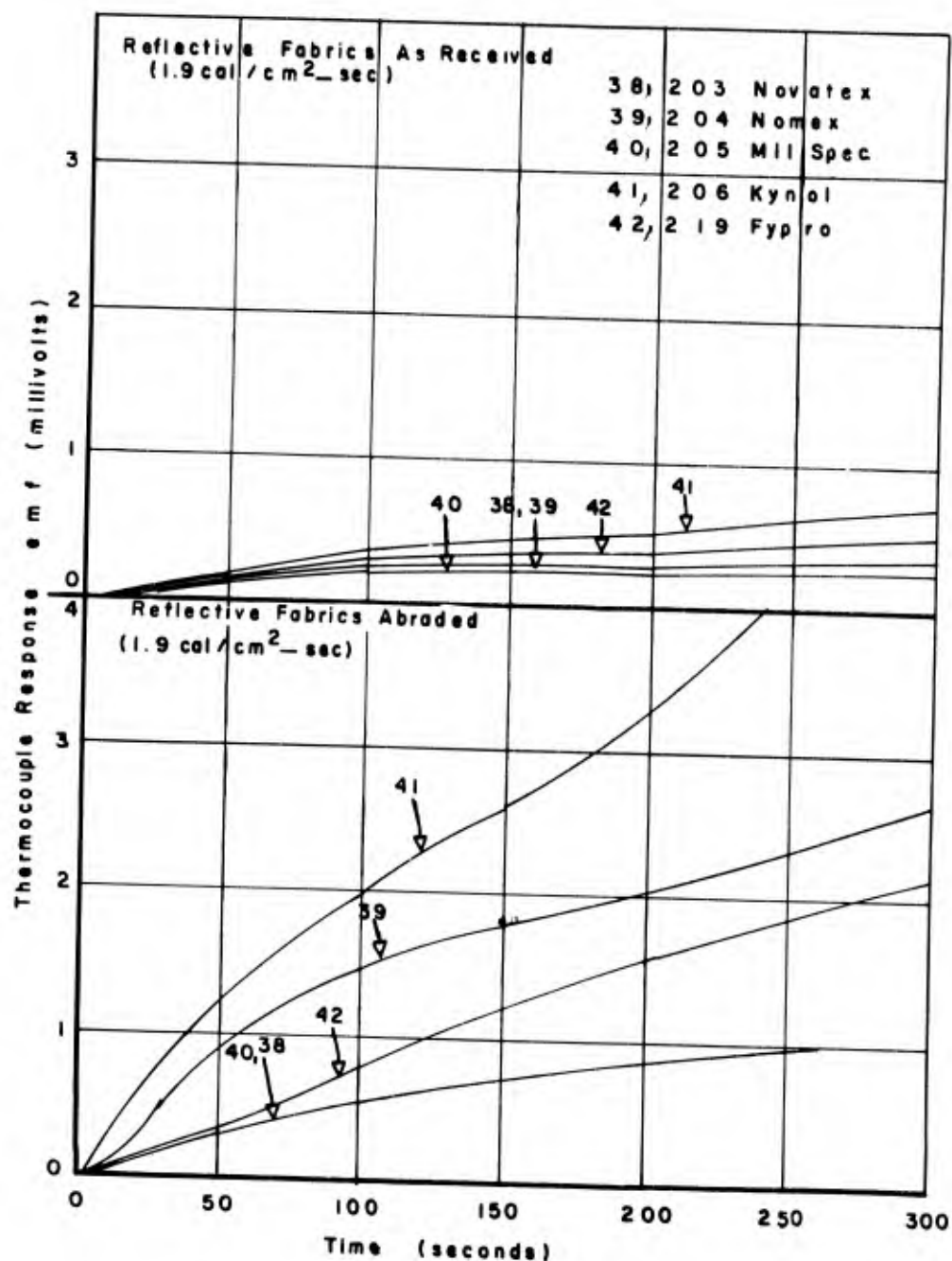


Figure 7. Reflective Fabrics Over Batting No. 202

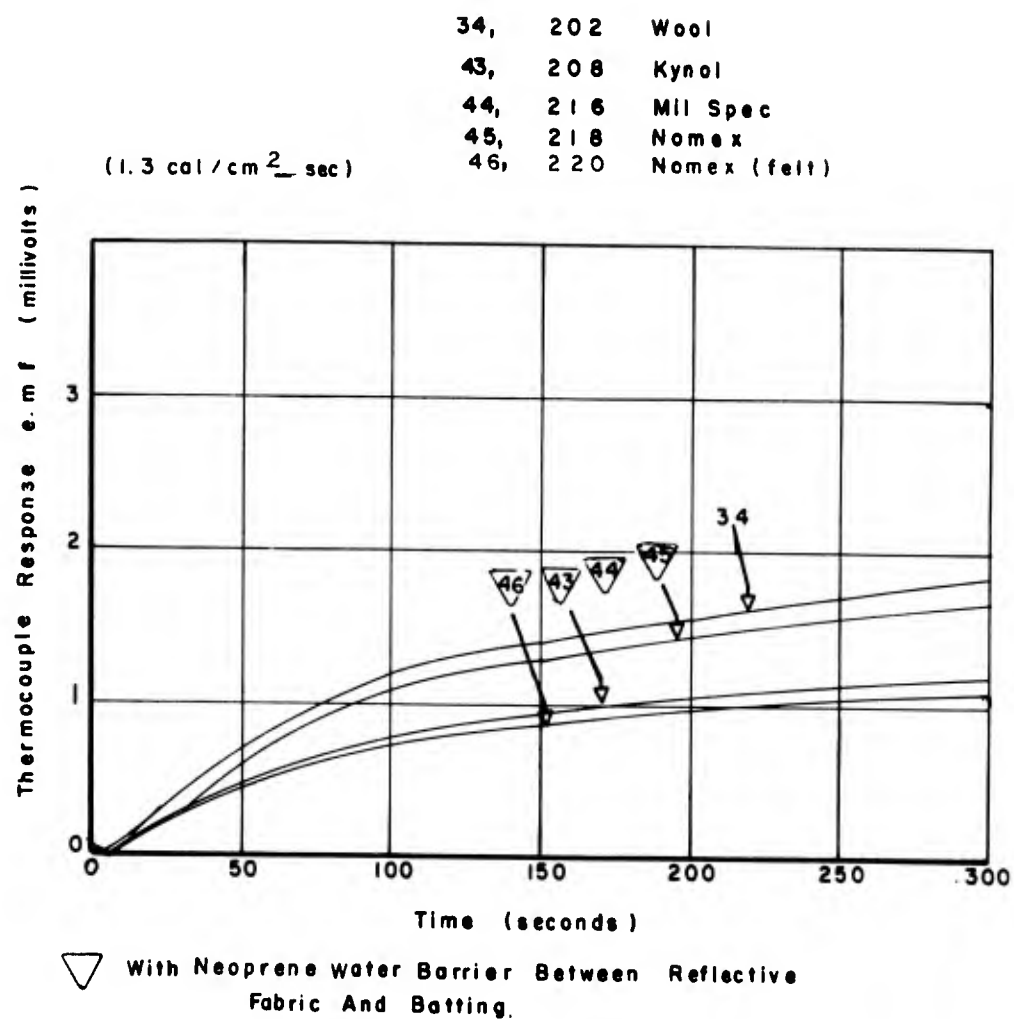


Figure 8. Battings - Covered w/Abraded No. 204

SECTION VI

CONCLUSIONS

Outer shell fabrics of the aluminized Novatex and Fypro fabrics in combination with a needle punched felt material will provide a high degree of protection from radiant heat, improved comfort and mobility when incorporated into fire fighter's fire proximity suits. A development program should be initiated to improve the abrasion resistance of the shell fabrics, especially their aluminum surface, and to investigate newly developed thermally stable fibrous materials such as PBI and Durette as base fabrics for aluminization and for insulating layers. Base fabric construction should also be optimized for improved fabric flexibility while maintaining fabric reflective characteristics.

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13. ABSTRACT Lightweight protective fabrics are needed for incorporation into fire fighter's proximity suits to provide protection, comfort, and increased mobility to the wearer while fighting liquid fuel (JP-4) fires. Candidate materials which are commercially available are evaluated on the basis of protection from radiant heating exposures and for flammability and mechanical properties. Novatex and Fypro shell fabrics in combination with a neoprene water barrier and a Nomex needle punch felt will provide a high degree of protection and increased comfort and mobility for wearers while fighting liquid fuel fires.		

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